ANCILLARY DATA SERVICES OF NASA's PLANETARY DATA SYSTEM

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ABSTRACT

JPL's Navigation and Ancillary Information Facility (NAIF) has primary responsibility for design and implementation of the SPICE ancillary information systcm, supporting a wide range of space scicncc mission design, obscrvation planning and data analysis functions/activities. NAIF also serves as the gcomctry and ancillary data node of the Planetary Data Systcm (PDS). As part of the PDS, NAIF archives SPICE and other ancillary data produced by flight projccts. NAIF then distributes these data, and associated data access software and high-level tools,to rcsearchcrs funded by NASA's Office of Space Scicncc. Support for a broader user community is also offered to the cxtcnt rcsourccs pcrmit. This paper dcscribcs the SPICE systcm and customer support offered by NAIF.

SPICE OVERVIEW

SPICE offers onc approach for producing, archiving and using ancillary data within a distributed information systcm architccturc. SPICE provides a portable, mulli-discipline mechanism uscful in both planning space scicncc observations and in reducing the data obtained from those observations. Within the SPICE contcxt, ancillary data arc broadly defined as those. uscd to dctcrminc:

- where an instrument was located while taking data,
- where the instrument was pointed and what targets it coul d scc,
- how those targcts would appear at the time of observation,
- how an instrument was acquiring data, and
- what clsc of significance to scicncc data analysis was occurring,

In this contcxt a "target" could bc a whole planet, satellite, comct or astcroid, a surface or atmospheric fcaturc, or a star. Targets on planct earth arc as valid as any others for appl ication of SPICE tcchnology.

SPICE Components

The principal components of the SPICE systcm arc a set of clcmcntal data files-called kcrncls- and softwarc. Some of the SPICE software is used to produce kernel filcs, some is used to manage those files, and the remainder is used to read those files to find information or calculate parameters nccdcd to plan observations or interpret sensor data. The contents of the SPICE components arc summarized in Figure 1. The reader can scc that the acronym might bcttcr have been "SPICES."

Making SPICE Kcrncl Files

Instances of each type of SPICE kernel file should bc produced by the entity most qualified to do so---the person or group most familiar with the components and proccsscs from which ancillary data arc produced. For example, a projcct's navigation tcam responsible for estimating the orbit of a spacecraft would bc responsible for producing SPK kernel files. Similarly the spacccraft control team would construct CK kcrncl files. Hcncc, NAIF provides the mechanisms and standards for producing SPICE kernels, but is generally not the producer of these products. (NAIF dots producc SPK and PcK files from generic data that is not necessarily associated with any flight project.)

Distributing SPICE Products

SPICE kernel files arc normally collected and cataloged in a central repository for sub.sequent distribution to end users. For a flight project the repository likely resides at the mission operations center for the duration of the project. Al the conclusion of the mission the ancillary data arc transferred to the NAIF node of the PDS for formal archiving. Customer orders received by NAIF arc filled from this archive.

NAIF Toolkit software is distributed by the NAIF Group generally dirctly to a customer, but sometimes by way of a flight project's configuration management team.

SPICE data and NAIF Toolkit sofdtware arc delivered to the user by whatever means is available and best suited to both parties. Worldwide electronic networks offer convenience and immediacy for smal l to modest data volumes. CD-ROM and write once CD (CD-R) also play a major role, while magnetic tapes and even diskettes may also be used.

Using SPICE Kernels and Toolkit Software

The scientist or engineer builds an application program to address his or hcr particular need, This program integrates appropriate subroutines from SPICELIB (SPICE LIBrary) -the principal component of the NA1 F Toolkit software—with the user's own subroutines.

Some SPICELIB routines provide access to the data within SPICE kernel files. For example, calling SPICELIB routine SPKEZ returns the position of a target relative to an observer at a user-spc.cified epoch. The "observer" is typically a spacecraft, but it could be any object for which ephemeris data is available within an SPK kernel file, including the earth. The "target" is typically a planet, satellite, comet or asteroid, but again, any ephemeris object can be used.

Other SPICELIB routines combine data extracted from SPICE kernels to produce derived (higher level) geometric parameters or related ancillary information needed to plan observations or to interpret science data. Spacecraft altitude, lighting angles and latitude and longitude, of an instrument's optical axis intercept with the target arc typical of the computations available within SPICELIB.

Subroutines in SPICELIB have multimission applicability. But each flight project may optionally have a small number of routines that arc unique to it- these arc provide.d in an extension of SPICELIB, such as GLL_SPICE for Galileo.

A diagram illustrating how SPICE may be used is shown in Figure 2. In this simplistic, unlikely situation data from a complete set of SPICE kernels arc used within a single program, along with the data from a scientist's instrument, to obtain scientific results. The drawing indicates that improved values for data found in kernel files could also be a product of the user's program, and these might be fed back into the SPICE archive (with appropriate documentation and after appropriate review).

CHARACTERISTICS OF THE SPICE SYSTEM

"Correct" Results Arc Obtained

It is imperative that, within realistic limits, an ancillary information system such as SPICE provide results that arc "correct". Whether or not a SPICE user gets the intended results depends on several factors.

- "Correct" and accurate data must be assembled for placement in SPICE kernel files.
- Software used to produce SPICE kernels and subsequently to read thcm and compute, derived quantities must be accurately specified and must perform as specified.
- SPICE kernel files must be correctly labeled.
- Kernel producers as well as kernel users must be able to determine with confidence which SPICELIB subroutines to usc to yield the intended results.

To a certain degree the correctness of ancillary data is subjective. Different customers may subscribe to different values for a fundamental quantity, such as the radius (or radii) of Titan. Customers may also require varying dcgrccs of precision; a radio scicntist is generally more demanding of prccisc time, range and vclocity computations than arc scientists associated with other disciplines.

Seeking out substantial, definitive customcr feedback seems tbc best mcthod of obtaining a compositc measure of corrcctncss covering the factors above, (For instance, the radio scicncc discipline dots need better support.) in this regard the SPICE systcm-in its current state--has its fair share of shortcomings. Ncvcrthclcss, most users report success with their SPICE-based applications. The growing number of repeat customcrs and referrals furthcr supports the sense of customcr satisfaction.

Easy to Usc

It would bc misleading to assert that SPICE is easy to use. But it may bc said that a substantial fraction of the resourccs invested in SPICE dcvclopmcnt have been applicd to documentation and tutorial materials crcatcd cxplicitl y for cnd users.These have helped over 400 SPICE uscrs achicvc their objectives. Ncvcrthclcss, improving and better organizing SPICE documentation remains a significant challcngc for the NAIF Group.

Portable Data, Portablc Softwarc

Portability of SPICE kcrncl files is achicvcd by using text-format files Several of thc kernel files cxist only in text format and so arc readily ported. Those kcrncl files that arc normally in binary formal arc translated to a portable cncodcd tcxt form named SPICE Transfer Format,using a portable NAIF Toolkit utility program, prior to being ported to a hctcrogcncous host. Thc same program is used to translate the file back to the binary formal. of the ncw host once the data have been moved there. This translation process takes a little extra time, and transfers involve more data (about 2.5X), but this simplc schcmc easily works across the many computer systems and nctworks in usc by scientists and cnginccrs.

SPICELIB uses ANSI FORTRAN 77 code, and while environmental dcpcndcncics cannot bc totally eliminated, they have been minimizcd, isolated and clearly documented. Changes nccdcd to port the NAIF Toolkit softwarc to several popular platform/ compiler combinations arc implcmcntcd and tested before the Toolkit is rclcascd to thc user community. The currcnt complement explicitly supported by NAIF is listed in Table 1. Several customcrs have used the porting instructions included with thc Toolkit to help port this code LO still other platforms, also shown in Table 1.

Platforms To Which NAIF Staff Have Ported The Toolkit	Platforms To Which Othcrs Have Ported the Toolkit
DEC VAX VMS	DEC VAX Ultrix
DEC Alpha OpcnVMS	1)ata Gcncral
DEC Alpha OSF/1	Cray
Hewlctt Packard 700	IBM mainframc/MVS
Sun	PC/LUNIX
Silicon Graphics	
PC/M.S. Professional FORTRAN	
PC/Lahcy EMS-32 FORTRAN	
Macintosh/Languagc Systems FORTRAN	
NeXT/Absofl FORTRAN	

Table 1. Examples of Platforms Where NAIF Software Is Operational

Many customers call NA1 F Toolkit routines from C programs since most compilers support cross-language compatibility. Some customers have inquired about tbc availability of the NAIF Toolkit in the C and C++ languages. These do not cxist, but the NAIF Group is giving some consideration to this question.

Flcxibilit y - Separable and Extcnsiblc Componcnts

To endure, a data systcm must bc easily adaptcd to mcct ncw or revised rcquircmcnts. While the SPICE kernels and the allied Toolkit softwarc arc designed to operate as an integrated systcm, subsets of SPICE also prove useful. Onc cxamplc of SPICE component separability can bc found in the widespread usc of SPK kernel files containing ord y planct and satellite ephemeris data (no spacecraft cphcmcris) for terrestrial obscrvation planning and for planning observations from missions such as the International Ultraviolet Explorer that don't usc SPICE.

Each kernel design had cxtcnsibility as a major objcctivc. Two approaches were used. For those kernels that arc text files, data arc formattcd in a simple but flexible **KEYWORD = VALUE** style. Ncw keyword/vah]c pairs can bc added as nccdcd. Dcscriptivc text that is ignored by kernel access softwarc can bc inserted whcrcvcr appropriate to document data pcdigrcc or any other useful information.

The binary kernels arc built upon speciall y dcvclopcd data structures that were designed to accommodatc growth. Each structure supports a family of data typcs, unlimited in number. As an example, the SPK kcrncl family currently consists of fourteen data types: Chcbyschcv polynomials, traditional conic elements and the Navy's so-callcd two-line clcmcnts arc the bascs for three of the.sc.

Affordable

Economic considerations- always important- toda y rcccivc cxtra attcntion from NASA managers. SPICE rates high in this regard, mostly bccausc of the flcxibility and wide applicability noted earlier. These qualities allow the cost of maintenance and cvolution to bc shared across a broad user base.

Equally important is the attcntion paid to ensuring that SPICE software maintenance costs will bc reasonable. The subroutines arc written in a consistent, easy-to-read st ylc and arc highl y annotatcd—approximately 70 pcrccnt of the source "code" is actuall y documentation, The NAIF staff refrains from using FORTRAN features that frequently make code difficult to maintain: examples arc COMMON blocks and EQUIVALENCE statements. But usc of a fcw extensions to the ANSI FORTRAN 77 standard which promotc code maintainability arc pcrmittcd in the local mastcr copy of the Toolkit. A prccompilcr can bc uscd to translate this codc into pure ANSI FORTRAN 77 before Toolkit dclivcrics arc made.

NAIF TOOLKIT CONTENTS

SPICELIB is the principal component of the NAIF Toolkit. Users of SPICE kcrncl files usually need little or no understanding of the file structures and specific contents since their intcrfacc to these datascts is always realized through the SPICE kcrncl file "reader" subroutines found in SPICELIB.

In addition to the kcrncl filc readers, SPICELIB contains a broad set of subroutines designed to further assist scientists with the planning or interpretation of space science. observations. Examples of the functional categories addressed by these modules arc time translation, rcfcrcncc frame and coordinate conversion, solid geometry, vcctor and matrix algebra, conic clcmcnt applications, string manipulation, parsing and array manipulation.

Beyond SPICELIB, the Toolkit contains "cookbook programs" that arc samples of typical usc of SPICELIB subroutines and functions. It also includes several important utility programs that provide conversion, summarizing and labeling functions for binary SPICE kcrncl files.

Several SPICE customers have dcvclopcd application programs that could bc useful to others. And the NAIF Group is also writing some applications intended to bc broadly useful. Intcrcstcd persons should check with the NAIF Group at JPL for details.

SPICE SYSTEM APPLICATIONS

The SPICE systcm has been built and tcstcd in a predominantly planetary scicncc cnvironmcnt; its usc in supporting scicncc observation planning and scicncc data analyscs in conjunction with planetary flight projccts is wcll established. SPICE has also been appl icd in other space scicncc disciplines. Table 2 summarizcs current and possible uscs.

Data Rcstorations or Archive Preparation	Current Applications	Futurc Possibilities
Viking *	Hubblc Telcscopc	Eos
Pioneer 10/1 1 *	Galileo	Pluto Fast Flyby
Voyagcr *	Mars Global Survey	Discovcry Program
Magcllan *	Mars Pathfinder	Solar Probe
Phobos 88 *	Mars 96	SIRTF
Ul yssccs *	NEAR	AXAF
Clcmcntinc	Radioastron/VSOP	Japanese 1 .unar and Mars missions
	Cassini	Ncw Millennium Program

* = limitcd set of SPICE data is blc

Table 2. Current and Possible SPICE Applications

SPICE is also used informally to support a variety of other programs and applications; scicncc operations support for the Russian Granat, Intcrbol and Spcctrum-X/G missions, observations from tcrrcstrial observatories, mission concept studies, and solar systcm dynamics analyses arc among these.

With each ncw application the scientists and cnginccrs already familiar with SPICE will find it easy to deal with proccsscs requiring the usc of ancillary data. For ncw SPICE applications, funding organizations will find the marginal cost for adapting and operating this proven information systcm to bc very rcasonablc.

PRODUCTS AND SERVICES OFFERED BY NAIF

The principal products and scrviccs offered to the planetary scicncc communit y arc listcd below. Thcsc arc offered primarily to rcscarchcrs supportcd by NASA's Office of Space Scicncc. Support for the broader community is provided as dircctcd by NAIF's NASA sponsors and as rcsourccs permit.

- Archival SPICE kernel files from complctcd missions. Scc Table 2 for a list of these missions.
- Data restoration into SPICE kernel formats (limitcd possibilitics)
- NAIF Toolkit
- Some general purpose applications dealing with SPICE data products
- Advice on building SPICJ3-based applications
- Assistance with solving problems cncountcrcd whcn using SPICE products

NAIF dots nol yet have on-line data ordering scrviccs or geometry calculation tools, but some may bc added in thc futurc.

Institutions funded by thc Russian Academy of Scicncc and the Russian Space Agency have adoptcd SPICE for usc on a varicty of Russian-managed international missions. SPICE products produced by the Russians will also bc available from thc JPL NAIF Group.

Dcvclopmct of the SPICE systcm was carried out by the Jet Propulsion laboratory, California Institutc of Tcchnology, under contract with the National Aeronautics and Space Administration,

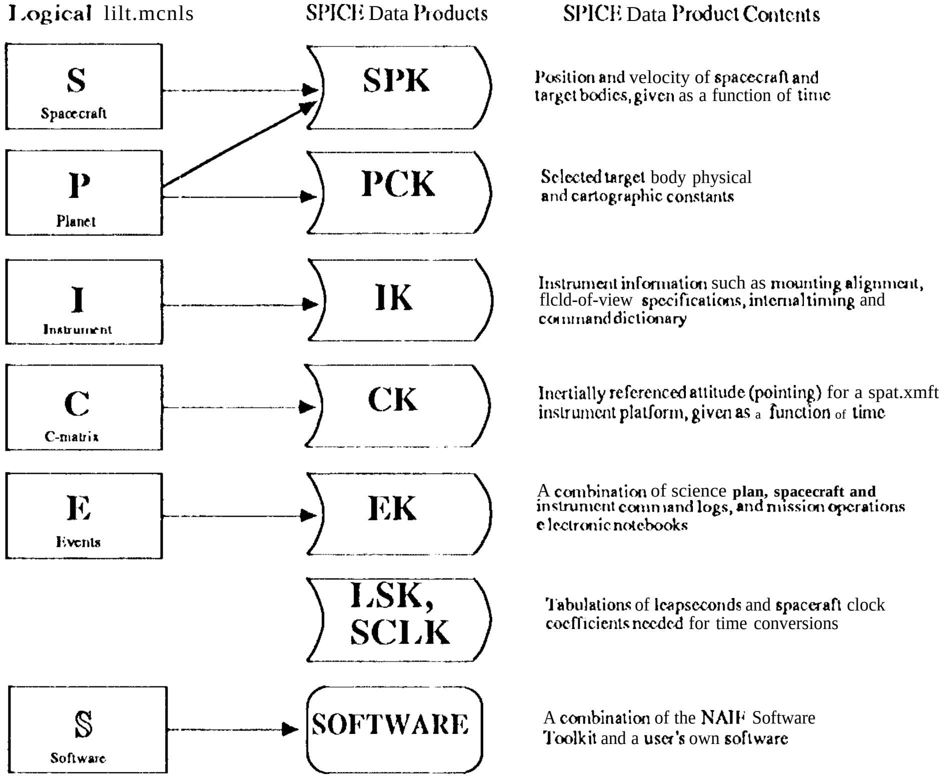
Logical lilt.mcnls
SPICE Data Products
SPICE Data Product Contents
S
Spacecraft
SPK
Position and velocity of spacecraft and target bodies, given as a function of time
P
Planet
PCK
Selected target body physical and cartographic constants
I
Instrument
IK
Instrument information such as mounting alignment, fleld-of-view specifications, internal timing and command dictionary
C
C-matrix
CK
Inertially referenced attitude (pointing) for a spat.xmft instrument platform, given as a function of time
E
Events
EK
A combination of science plan, spacecraft and instrument command logs, and mission operations electronic notebooks
LSK, SCLK
Tabulations of leapseconds and spacecraft clock coefficients needed for time conversions
S
Software
SOFTWARE
A combination of the NAIF Software Toolkit and a user's own software

Figure 1. Principal Elements of the SPICE System

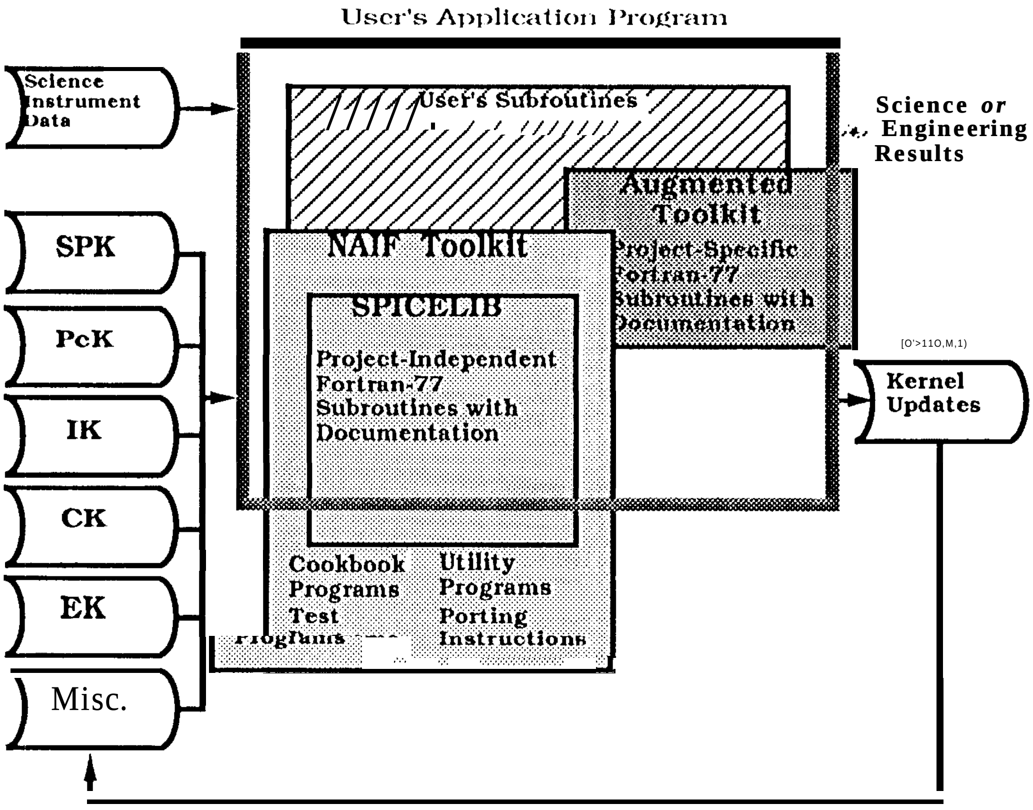

Figure 2. Using SPICE Kernel Files and NAIF Toolkit Software